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Original Article

Climate Change and Variability (1989 to 2019) and their Impact on Finger Millet (Eleusine coracana) Productivity in Kericho County

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Climate Change, Finger Millet (Eleusine coracana), Climate Variability, Productivity, Kenya Meteorological Department, SPSS, NVIVO, Trend Analysis, Statistical Significance, Precipitation, Rainfall Variability, Average Temperature, Regression Model, P-value, Statistical Significance, R Programming Language.

ABSTRACT

Native foods have salient socio-cultural significance among many communities in Africa. In Kenya, certain food crops are important for cultural ceremonial functions. However, the food crops are relatively under threat in their availability due to climate change impacts and development. Finger millet (Eleusine coracana) is one of these traditional food crops. The main purpose of this study was to examine the impact of climate change variability on the productivity of finger millet which is culturally significant among the people of Kericho County. The climate data was obtained from the Kenya Meteorological Department, Kericho station. The statistical package for social sciences (SPSS) statistical tool was used to analyse the quantitative data obtained. Trend analysis from the focus groups was chronicled by notes taking and analysed using the NVIVO analytical tool, which analysed both qualitative and quantitative data. Results were discussed and presented in charts, tables and graphs. The responses were tested by adopting a statistical significance of $p \leq 0.05$. The R programming language analysis of temperature revealed an upward trend in the annual average temperature levels for the entire county over the period of interest. The results showed that precipitation has been erratic and fluctuating over the years. A general trend, however, indicated an overall decline in rainfall over the years of interest. The regression model analysis for the relationship between rainfall variability and average temperature on finger millet productivity since p-value = 0.041 and <0.05 at 95% confidence level, Precipitation/Rainfall has a positive significant impact on finger millet productivity. Also, p-value = 0.027 for Average Temperature implies there is statistical significance.

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INTRODUCTION

The negative influence of climatic change is gradually being felt globally; this includes elevated temperatures and rainfall, alterations in amount, timings, and geographic distributions and increased droughts and floods, rising sea levels. They have damaging consequences on agriculture, biodiversity and ecosystems (Reddy, 2015). Whereas crops in selected areas of the universe may have progressed, rural poor unindustrialized economies like Africa, that experience food shortages, are liable to suffer the maximum austere outcomes and require adjustment interventions and development backing to survive fluctuating environmental conditions (Keane et al., 2009). Changes in climate threaten Kenya's attainment of its growth objectives envisaged in Vision 2030 due to vulnerability to climate-linked menace (Newell, Taylor, & Touni, 2018). Climatic appraisal indicates elevated temperature variability and substantially reduced rain, particularly planting period, leading to peculiar extended dry bouts (Yanda & Mubaya, 2011). Kericho County records the maximum incidence of hailstorms annually concurring with Guinness World Records (Glenday, 2013).

The main objective of this study was to examine rainfall and temperature trends in Kericho County from the years (1989 to 2019) and to determine the impact of climate change and variability on the productivity of finger millet in Kericho County.

Climate Change and Finger Millet Crop

There is consensus that the impacts of climate change on agriculture will add significantly to the development challenges of ensuring food security and reducing poverty, particularly in Africa (Yanda & Mubaya, 2011). Climate change is a serious threat to crop productivity in regions that are already food insecure. Studies conducted by (Knox et al, 2012) projected a mean change in yield of all crops to be -8% by the 2050s in Africa and South Asia. Across Africa, mean yield changes of -17% wheat, -15% sorghum, -5% maize, and -10% millet. Complex simulation studies that used biophysical crop models showed the greatest variation in mean yield changes. Evidence of crop yield impact in South Asia and Africa is robust for millet, wheat, sorghum and maize (Knox et al, 2012). A study done in southwest Niger by (Marteau et al., 2011) between the years 2004 and 2009 revealed that the productivity of pearl millet is affected by the onset and cessation of rains. A field survey of on-farm sowing practices was conducted with the aim of investigating the relationships; between rainfall and the sowing date of pearl millet and the risk of sowing failure, between sowing and agro-climatic/ meteorological onset dates, between sowing/onset dates, and simulated and observed yield/biomass at the end of the season. It was concluded by Marteau et al., (2011) that there is a tendency for weaker amounts of biomass and weaker yields because of the late onset of rain. Crop simulations however showed that sowing very early, for example during or just after the first wet spell

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when at least 90% of rainfall stations receive simultaneously at least one mm in two consecutive days, does not necessarily exploit simulated yield because of the high risk of long-lasting post-onset dry spells. Studies by Leblois et al., (2014) concluded that bad seasons of rain have an immense impact on the yield of crops and recurrently result in food crises. According to Leblois, insurance policies may slightly intensify the use of risk-increasing inputs such as fertilizers and improved cultivars and hence improve average yields, which remain very low in the region. According to (Marteau et al., 2011), the strategy of the farmers is sowing their field during or just after the first significant wet spell combined with using varieties that are photoperiodic to provide the best-suited response to the spatial and temporal variability of the onset of the rainy season.

MATERIALS AND METHOD

A transdisciplinary approach was used in this study where participatory focus group discussions and household surveys were utilized to get the perspectives of the community on the changes in climate and food security. Community leaders and professionals such as officials from the Ministry of Water, Ministry of Agriculture and NEMA; agronomists, Civil Society Organizations (CSOs) and NGOs were actively involved in the study. The sample for the study involved farmers who are the heads of households in the rural set-up of Kericho County. The formula by (Yamane 1967) formula was used in determining the size of the sample:

$$n = \frac{N}{1 + N\,(e)^{2}}$$

Where N is the size of the population, n is the size of the sample while the precision level is (0.05) and represented by e. The size of the sample was obtained through the substitution of letters in the formula with values. The total population of Kericho County is 901,777, therefore.

N =901,777

n = Sample size

e = level of precision

$$n = \frac{901777}{1 + 901777(0.05)^{2}}$$

n = 399.82

Therefore, the actual size of the sample for the study obtained from the formula was four hundred.

The study incorporated mixed methods this is because; utilizing both qualitative and quantitative data enhances an evaluation by ensuring that the strengths of one type of data are protected against the weaknesses of another. Quantitative primary data for temperature and precipitation was collected from the Kericho meteorological station. Data analysis employed the statistical package for social sciences (SPSS), where inferential and descriptive statistics were obtained. Qualitative data on the other hand were obtained from narratives that the farmers who are the climate change witnesses gave. Data presentation was done using graphs, tables and texts.

The collection of qualitative data for the impacts of climate change and variability on finger millet productivity was from individual interviews, participatory focus group discussions and observation of participants. Secondary data was obtained from documented literature. Techniques/tools used included written description, video recordings and photography. This data was transcribed and analysed using content/thematic analysis. Quantitative data was analysed using SPSS while qualitative data employed the r- programming language analysis tools as well as NVIVO software, a software program used to analyse qualitative and mixed-methods research.

RESULTS

Rainfall and Temperature Trends in Kericho County (1989 To 2019)

This section presents rainfall and temperature trends in Kericho County from the years (1989 to 2019) depending on the return rate of the research tools used. The purpose of the study is to examine the impacts of climate variability on the

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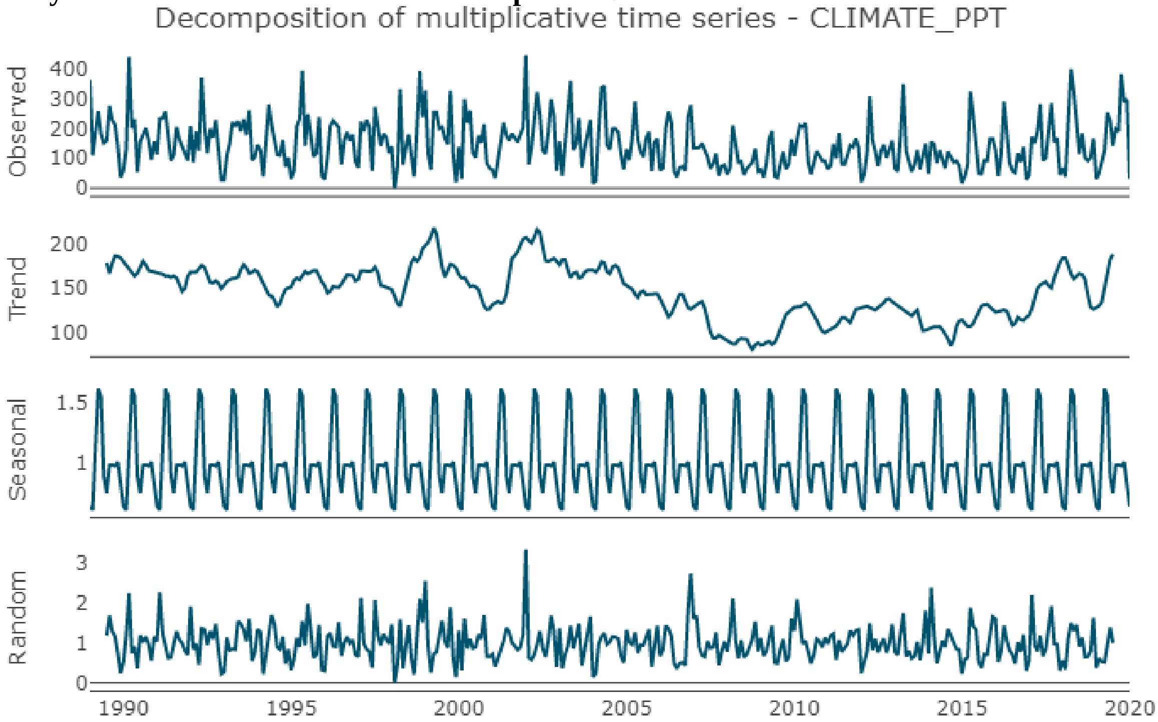
productivity of finger millet in the county of Kericho. The data for rainfall and temperature trends were obtained from the Kenya Meteorological Department where it was then analysed.

Figure 1: Annual, Monthly and Seasonal Rainfall Trends for the year 1989-2019 in Kericho are Analysed and Presented in Trend of Precipitation.



Source: *Research Data (2020)*

The results illustrated in Figure 1 depict fluctuating precipitation trends in Kericho County over the years of study. However, a relatively stable pattern can be observed between 1989 and 1998 where rainfall variations are observed ranging between around 140 mm to 207mm per year. Extreme rainfall patterns, ranging from about 130mm and 250mm per annum are observed between 1999 and 2004. From 2005 onwards rainfall has been fluctuating, unpredictable and quite erratic.

In addition, the precipitation trend of Kericho County indicates a general decrease in rainfall over time as indicated in Figure 2.

Precipitation rolling mean and rolling standard deviation data indicate that precipitation in Kericho County is not exhibiting a stationary trend at the first lag i.e. P-Value=0.01 hence less than 0.05.

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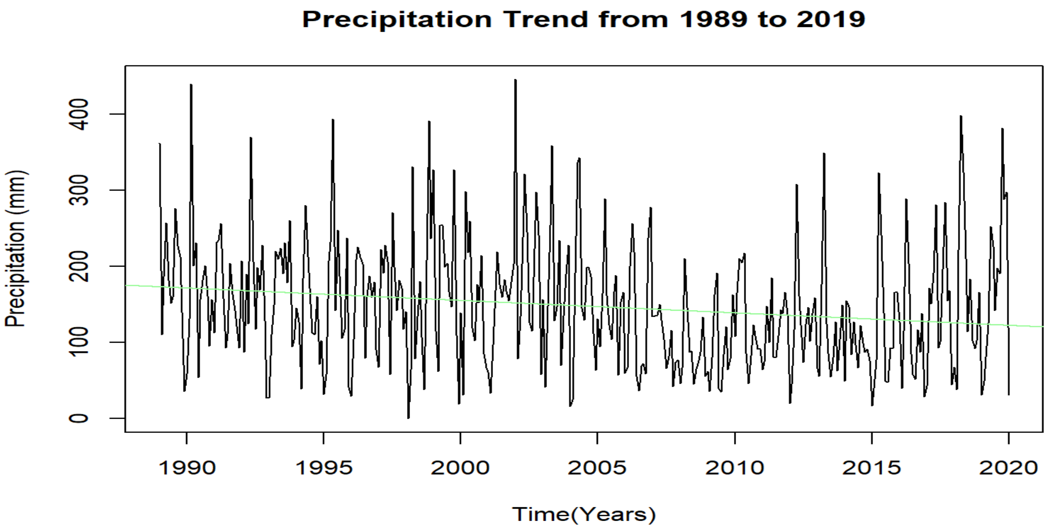
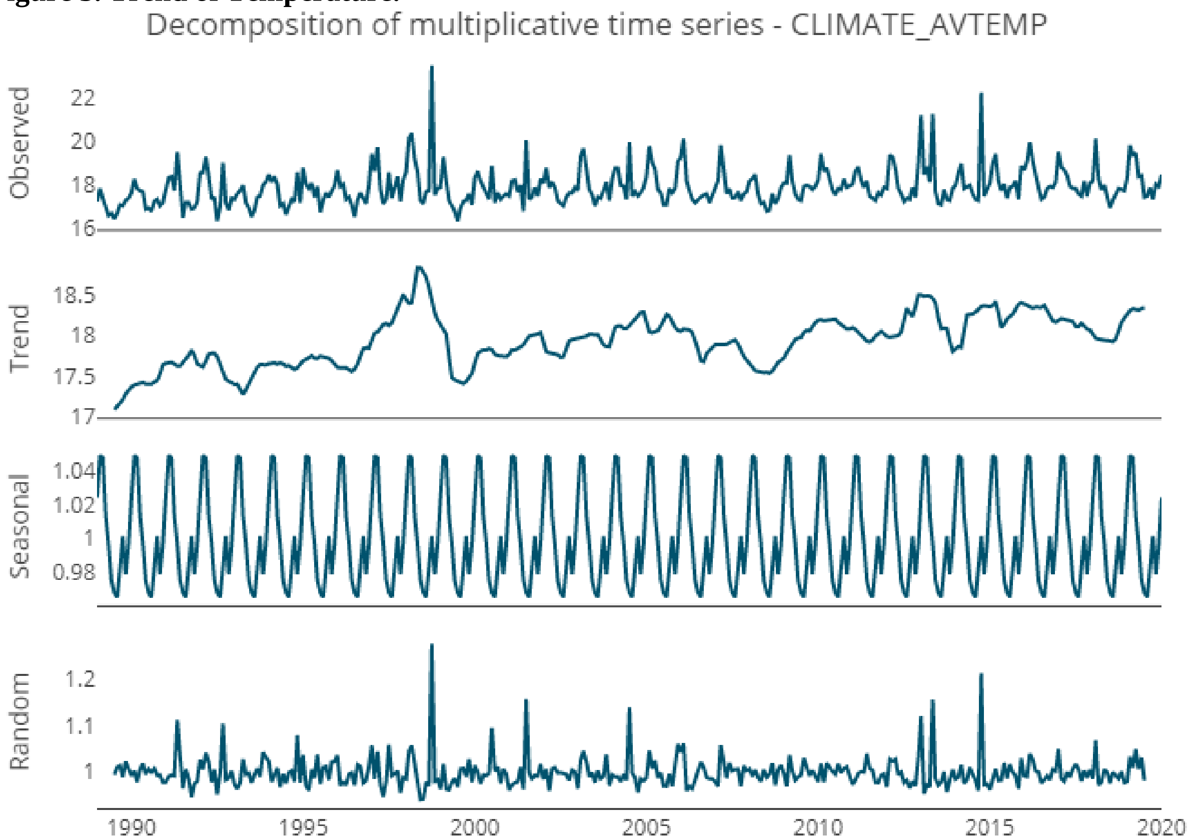
Figure 2. Plot of Precipitation versus Time.



The time series plot produced by R reveals the presence of a downward trend in the annual precipitation levels for the entire county over the period of interest.

General Trend of Temperature over the Study Period.

Figure 3. Trend of Temperature.



Source: Research data (2020)

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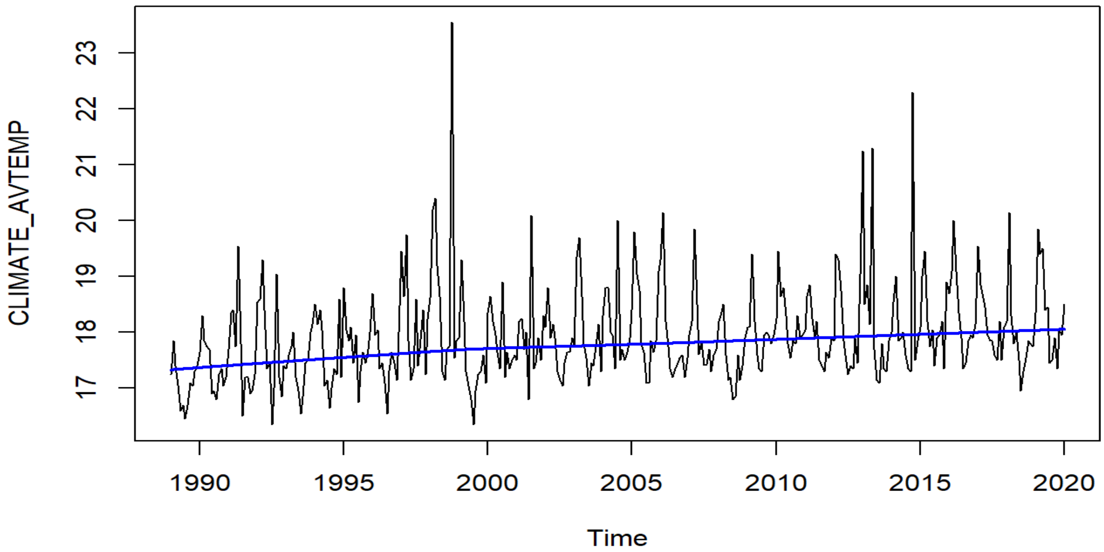
The results illustrated in Figure 3, show that the temperature trend in Kericho County has been fluctuating over the years. However, a relatively moderate pattern can be observed between 1989 and 1995. Extreme temperature variations were recorded around 1997 and 1999, ranging around 17.5^0 C and 18.5^0 C per annum. From around 2005 onwards Annual temperature trends of Kericho County indicate that the county is steadily getting warmer.

Figure: 4. Average Temperature Trend.



Source: researcher 2020

The time series plot illustrated in Figure 4 produced by R, reveals the presence of an upward trend in the annual average temperature levels for the entire county over the period of interest. To better see this trend, a nonparametric loess curve to the data using the lowest function in R was fit and the resulting plot revealed the underlying upward trend present in the data more clearly.

The Effect of Rainfall and Temperature Variability on Finger Millet (Eleusine coracana) Productivity in Kericho County.

The lower regions of Soin, Sigowet and Kipkelion West counties receive depressed rainfall which affects finger millet production, as reported by a key informant (KI), (the Quality Assurance and Standards Officer, Kenya Climate Smart Projects Kericho County). Heavy and extended rainfall especially during harvesting results in high post-harvest losses caused by grain moulds and seed germination hence loss of nutrients since they get depleted. Heavy rains have also affected the traditional land preparation process of burning soil, hence leading to reduced productivity. Winch, (2006) confirms that frostbite is so devastating particularly Head Smut and Leaf Rust which are the major diseases responsible for low yields in Millet in Kericho County. These harsh weather conditions sometimes lead to total yield loss and emerging of high pest and disease incidences; especially a fungal disease locally called (*chelaliit*) directly translated from 'burnt ear' a name given to a condition characterized by drying of some finger millet heads just after flowering leading to complete failure in seed development (Bett, 2018). The condition results in reduced productivity per unit, high losses and low returns.

Information was collected from the participatory focus group discussions, where estimated productivity per 10th acre was done in the last three decades (1989-2019). The data was analysed using the R programming language analysis and

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presented in Table 1 below. Comparison between rainfall trend and finger millet productivity was also estimated and findings are presented in Table 1 and Figure 5.

Figure 5. Rainfall Variability and Finger Millet Production.

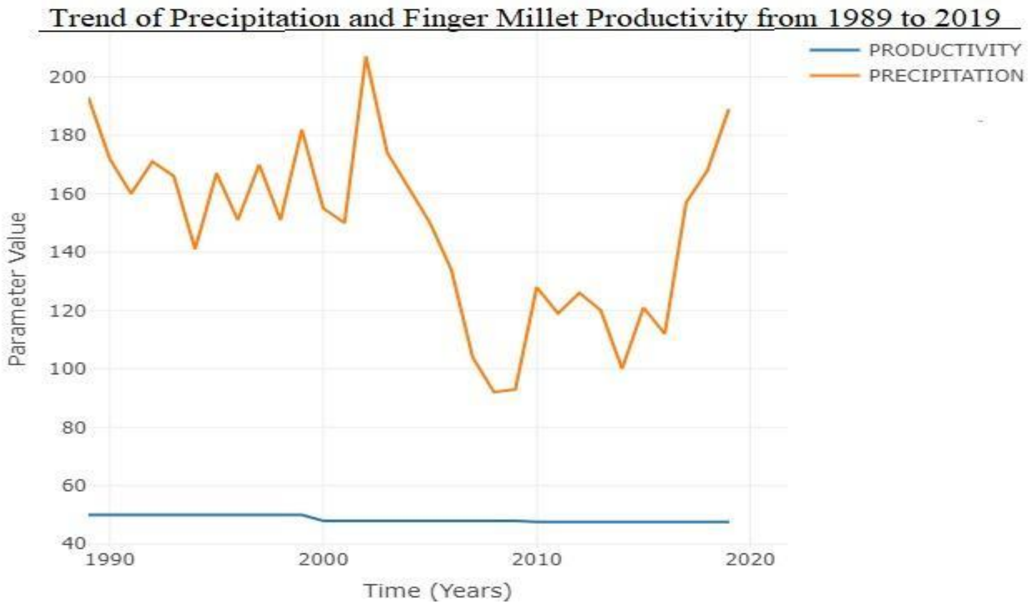

Figure 5. Illustrates a decrease in finger millet productivity over the years from 1989 to 2019 because of variations in rainfall/precipitation. Productivity was estimated to be about 50 kilograms per tenth of an acre from 1989 to 2000. A decline in the productivity of finger millet (below 50kg per acre) was observed from around 2000 onwards. A member of one FGD in Ainamoi Sub County reported that "*In the past people planted finger millet before planting Maize, but nowadays climatic changes have forced farmers to wait. For instance, this year (2020) I planted maize before finger millet because there were heavy rains in March so I delayed planting to avoid the chilly seasons locally known as (Kiptungit) i.e. months of June/July which make the finger Millet heads to burn hence reducing yields.*"

Table 1: Summary of Annual Data on Productivity and Precipitation

INDEX	PRODUCTIVITY (kgs. Per 0.1 of an Acre)	PRECIPITATION (mm)
Maximum	50.0	207.0
3rd Quartile	50.0	169.0
Mean	48.6	147.9
Median	48.0	151.0
1st Quartile	47.6	123.5
Minimum	47.6	92.0

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Finger millet production has been declining over the years. It was also reported that traditionally, farmers used to burn topsoil in fields where finger millet was to be planted. This practice has since been abandoned due to climate change leading to increased labour in weed management. A member of one of the FGDS explained that

> "*In the past, we used to know our planting season through the movement direction (Migration) of some migratory birds locally known as (Cheptalaminik) in our native language. We no longer see birds that used to fly from north to south marking land preparation season and south to north marking finger millet planting season. But nowadays we use months because people have acquired formal education"*

Linear Regression Analysis

Figure 6. Validation of Linear Model Regression Using Global Validation of Linear Models Assumptions (GVLMA) Package

```
## Call:
## lm(formula = PRODUCTIVITY ~ PRECIPITATION + AVERAGE_TEMPERATURE,
##     data = MODEL)
## Residuals:
##     Min      1Q Median      3Q     Max
## -1.4544 -0.6023 -0.1701 0.6011 2.5651
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 66.573583   8.788427   7.575 2.99e-08 ***
## PRECIPITATION       0.012370   0.005775   2.142    0.041 *
## AVERAGE_TEMPERATURE -1.105611   0.473628 -2.334    0.027 *
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## Residual standard error: 0.911 on 28 degrees of freedom
## Multiple R-squared:  0.3389, Adjusted R-squared:  0.2917
## F-statistic: 7.177 on 2 and 28 DF, p-value: 0.003045
## ASSESSMENT OF THE LINEAR MODEL ASSUMPTIONS
## USING THE GLOBAL TEST ON 4 DEGREES-OF-FREEDOM:
## Level of Significance = 0.05
## Call:
## gvlma.lm(lmobj = r1)
## Value p-value              Decision
## Global Stat       7.6612 0.10481 Assumptions acceptable.
## Skewness          3.3389 0.06766 Assumptions acceptable.
```


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Kurtosis 0.3954 0.52945 Assumptions acceptable.

Link Function 2.2397 0.13451 Assumptions acceptable.

Heteroscedasticity 1.6873 0.19396 Assumptions acceptable.

28 23.236 0.830

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

PRODUCTIVITY(Y) = 66.573583 + 0.012370(PRECIPITATION) - 1.105611(AVERAGE TEMPERATURE)

Linear Regression Model Output discussion from Figure 6.

Model Formula:

PRODUCTIVITY ~ PRECIPITATION + AVERAGE_TEMPERATURE This formula means that the model is predicting PRODUCTIVITY using two independent variables: PRECIPITATION and AVERAGE_TEMPERATURE.

Residuals:

- Min: -1.4544
- 1st Quartile (1Q): -0.6023
- Median: -0.1701
- 3rd Quartile (3Q): 0.6011
- Max: 2.5651

These values represent the differences between the observed and predicted values. A symmetric distribution of residuals is generally desirable for linear regression. The residuals here are spread between negative and positive values, with the median being close to zero, suggesting no major systematic errors in predictions.

Coefficients (Estimates of the Model Parameters):

Intercept: 66.573583. The intercept is the predicted value of productivity when both precipitation and average temperature are zero. The p-value (2.99e-08) is very small, indicating that the intercept is statistically significant. Precipitation: 0.012370; This coefficient means that for each 1-unit increase in precipitation, productivity is expected to increase by 0.012370, assuming all other variables are constant. The p-value (0.041) is less than 0.05, suggesting that this relationship is statistically significant at the 5% level. The average temperature is -1.10561, this negative coefficient indicates that as the average temperature increases, productivity decreases, assuming the other variables remain constant. The p-value (0.027) is also less than 0.05, suggesting that this relationship is statistically significant.

Multiple R-squared: 0.3389, approximately 33.89% of the variance in productivity is explained by the model. This is relatively low, meaning that other factors not included in the model may be influencing productivity. Adjusted R-squared: 0.2917, this value adjusts for the number of predictors in the model. It is a more conservative estimate than r-squared and indicates that about 29% of the variation in productivity is explained by precipitation and average temperature. F-statistic: 7.177 (p-value: 0.003045), the F-statistic tests whether at least one of the predictors (Precipitation or Average temperature) significantly explains variation in productivity. The p-value (0.003045) is less than 0.05, meaning the model is statistically significant.

Model Significance: The linear regression model is statistically significant. Both precipitation and average temperature significantly affect productivity.

Since p-value = 0.041 and <0.05 at 95% confidence level, Precipitation/Rainfall has a

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positive significant impact on finger millet productivity. Also, p-value = 0.027 for Average Temperature implies there is statistical significance. Changes in rainfall affect soil water availability to finger millet while frostbite caused by fluctuations in temperature tremendously reduces the level of finger millet produced. Lack of adequate rainfall/prolonged drought seasons leads to the drying of finger millet, hence causing a decline in finger millet harvests. Heavy rainfall leads to the carrying away of important nutrients in the soil, causing soil erosion as well as carrying away finger millet plants, especially while still young.

Plate 1. Finger Millet Affected by Frostbites and Fungal Infection in Ainamoi Sub-County.

Plate 2. A Photograph of a Finger Millet Farm Taken at Kipkelyon East Sub-County.

Plate 1. Changes in rainfall affect soil water availability to finger millet while frostbite caused by fluctuations in temperature tremendously reduces the level of finger millet produced. Plate 2 illustrates a farm at Kipkelion East Sub County where plants were destroyed and others carried away by floods after heavy downpours in April 2020. Frostbites tremendously reduce the level of finger millet produced. Farmers reported that due to extreme temperature variations experienced lately, frostbite events are equally increasing tremendously.

Effect of Rainfall Variability on Finger Millet Production

Table 2: Effect of Rainfall Variability on Finger Millet Production

	1	2	3	4	5	Mean	Std. Deviation
Variability in rainfall affects water in the soil availability hence Finger Millet Productivity	0.0	0.0	0.0	0.0	100.0	5.000	0.000
Frost reduces Finger Millet Yields	0.0	0.0	0.0	0.0	100.0	5.000	0.000
Heavy rainfall destroys Finger Millet during germination and those ready for harvesting	0.0	0.0	0.0	83.3	16.7	4.166	0.389
Scanty rainfall on planting leads to a low rate of germination	0.0	0.0	16.7	83.3	0.0	3.833	0.389
Heavy rains lead to erosion of topsoil and wash away Finger Millet and fertilizers	0.0	0.0	0.0	16.7	83.3	4.833	0.389

Key; 1 Strongly Disagree, 2 Disagree, 3 Neutral, 4 Agree, 5 Strongly Agree

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The farmers indicated their agreement levels with different statements on rainfall variability and finger millet production. Where 1 was used to represent strongly disagree, 2 represented agree, 3 represented neutral, 4 represented agree and 5 represented strongly agree. From the findings, all the farmers (100%) strongly agreed with the statements indicating that variability in rainfall affects water availability in soil hence finger millet productivity and all farmers also strongly agreed that frostbite significantly reduces finger millet production and yields. Generally, changes in rainfall affect soil water availability to finger millet and frostbite tremendously reduces the level of finger millet produced (Landers., 2007) agrees with the statement. This is because lack of rainfall leads to the drying of finger millet. In addition, 83.3% of the farmers agreed while 16.7% strongly agreed with the statement indicating that heavy rainfall destroys finger millet during germination and those ready for harvesting, a statement supported by (Mgonja et al., 2013). Heavy rainfall leads to the carrying away of important nutrients in the soil, causing soil erosion as well as carrying away finger millet plants, especially while still young. In addition, it leads to the destruction of finger millet. Further, 16.7% of the farmers agreed while 83.3% moderately agreed with the statement that scanty rainfall on planting leads to a low rate of germination. The Ministry of Agriculture confirmed that the unpredictable weather patterns that have been observed in the county have affected finger millet production.

Effect of Temperature Variation on Finger Millet Production

Table 3. Effect of Temperature Variation on Finger Millet Production

	1	2	3	4	5	Mean	Std. Deviation
Temperatures have an important effect in increasing transpiration rates	0.0	0.0	0.0	50.0	50.0	4.500	0.522
Extreme cold conditions are detrimental to Finger millet production and may cause frost	0.0	0.0	16.7	83.3	0.0	3.833	0.389
Extreme hot conditions significantly reduce finger millet germination rate	0.0	0.0	0.0	33.3	66.7	4.667	0.492

Key; 1 Strongly Disagree, 2 Disagree, 3 Neutral, 4 Agree, 5 Strongly Agree

The farmers were requested to indicate their agreement level with different statements on temperature variability and finger millet production. Where five was used to represent strongly agree, four represented agree, three neutral, two agreed and one represented strongly disagree. From these findings, half of the farmers (50%) strongly agreed while 50% agreed with the statements indicating that variability in temperature has a significant effect in modifying transpiration rates/water losses hence finger millet productivity, this agrees with (Farooq, et al., 2012) that drought stresses affect transpiration rate in plants hence their productivity. 83.3 % of the farmers agreed that extreme cold conditions are detrimental to finger millet production and may cause frost bites significantly, leading to reduced finger millet production and yields the same way it affects tea production (Cheserek et al., 2015). In addition, 33.3% of the farmers agreed while 67.7% strongly agreed with the statement indicating that extremely hot conditions significantly reduce finger millet germination rates. The Ministry of Agriculture confirmed that the unpredictable weather patterns that have been observed in the county have affected finger millet production. One of the finger millet farmers in Kebeneti Division narrated that,

> *"in the past early rains were in February therefore March (Kiptamo) had always been the month of planting. January was dry and good for preparing finger millet fields by burning the top layer (tindinyek) but this year (2020) just like the past few years in this decade was disrupted by heavy rains. Nowadays there is no burning of the topsoil layer because of rains and lack of virgin lands. These rains have led to floods and*

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> *erosion that have swept away a lot of crops. Planting seasons have therefore been delayed throughout the year which exposes millet to diseases and frost, (chelalitt).*

Long rains have become quite erratic with delayed onset and abrupt cessation; Rains have become erratic and quite unpredictable as explained by one of the farmers in Bureti Sub County, "*These rains have led to floods and erosion that have swept away a lot of crops"*

Short rains are extending from September to January. Plant pests and diseases are becoming more common.

CONCLUSION

The research findings illustrate fluctuation in precipitation trends in Kericho County over the years of interest. In addition, the precipitation trend of Kericho County indicates a general decrease in rainfall over time as indicated. Temperature trends in Kericho County have been fluctuating over the years. However, a relatively moderate pattern can be observed between 1989 and 1995. The R programming language analysis of temperature reveals the presence of an upward trend in the annual average temperature levels for the entire county over the period of interest. In summary, the linear regression model is a reasonable fit, and the assumptions underlying it hold up well. However, the model's relatively low R-squared value suggests that other variables could potentially explain more of the variation in productivity. The findings clearly indicate that there is a significant impact of extreme temperature and rainfall changes on finger millet productivity. The findings agree with (Krishnamurthy et al., 2012) that rising temperatures and declining rainfall patterns are detrimental to crop yields, especially cereals such as maize and finger millet, which require more water. This leads to a reduced food supply as well as overall availability of food. Since p-value = 0.041 and <0.05 at 95% confidence level, Precipitation/Rainfall has a positive significant impact on finger millet productivity. Also, p-value = 0.027 for Average Temperature implies there is statistical significance.

Recommendations

The study found that extreme temperatures, both high and low, negatively affect finger millet production in the county of Kericho. This study recommends that research institutes such as Kenya Agricultural Livestock and Research Organization (KALRO) should research and develop better varieties of finger millet with lower sensitivity to temperature and rainfall variability.

The study also found that extreme rainfall like frequent drought and floods has a negative effect on the productivity of finger millet in the County of Kericho. The study recommends that finger millet farmers should adopt adaptation strategies such as changing planting seasons as well as adopting two planting seasons in a year to improve yields. In addition, farmers should use other strategies such as the installation of drip irrigation to provide water to the seedlings during the dry seasons. In addition, to reduce the risk of flooding, farmers should intercrop finger millet with other stronger crops such as maize. The study found that extreme hot conditions may increase disease prevalence as well as pest infestation hence decreasing both quantity and quality of finger millet productivity. The study therefore recommends that farmers should use pesticides to deal with pest infestation during the dry seasons. This should be done through a combination of chemical, biological and physical pest management methods.

Acknowledgement

This study was limited to the effects of climate variability on finger millet production in the county of Kericho. The study was limited to one County, findings can therefore not be generalized to other finger millet producing counties in Kenya. This study was limited to two climate components those were temperature and rainfall. For this reason, other studies should be conducted on the effect of soil and soil properties on finger millet production in the County of Kericho. A comparative study should be conducted on climate variability in finger millet producing Counties like Migori, Kisii and Kisumu among others. In addition, the findings of this study cannot be

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generalized to other types of farm products. This is because different crops require different climatic conditions. Therefore, further studies should be conducted on the effect of variability in climate on the production of other farm products such as sorghum, beans, flowers, maize and even livestock and their production.

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